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BELOW DECKS ELECTROMAGNETIC SURVEY STUDY - PHASE 1.(U)

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BELOW DECKS ELECTROMAGNETIC SURVEY STUDY - PHASE 1

Prepared For
OFFICE OF NAVAL RESEARCH
Department of the Navy
800 North Quincey Street
Arlington, Virginia 22217

6 August 1982

Final Technical Report

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This report contains the results of the Phase 1 effort of the Below Decks Electromagnetic Environmental (EME) Study for United States Navy Ships. In this effort a description of how the below decks electromagnetic environment is affecting various shipboard systems, especially

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ABSTRACT

This report contains the results of the Phase 1 effort of the Below Decks Electromagnetic Environmental (EME) Study for United States Navy Ships. In this effort a description of how the below decks electromagnetic environment is affecting various shipboard systems, especially on the newer classes of ships, is discussed. Present specifications and their application have been inadequate in dealing with the problems created by the environment. A model has been developed to describe the below decks environment from HF transmit antennas. The prediction results of the model are compared to measured data from the FFG-7 class. Measurement techniques for collecting data on the FFG-7 and DD-963 class along with a task plan for a Phase 2 effort has been developed and is presented. A test plan for shipboard measurements is also presented.

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1. INTRODUCTION

The purpose of the technical work described in this report is to develop analytical techniques to predict the electromagnetic environment (EME) in the below deck areas of United States Navy ships.

The work effort was designed to be performed in two phases. Phase 1, which is reported in this document deals with four distinct areas. They are the development of measurement techniques, model synthesis, an overall task plan for a Phase 2 effort, and a test plan for shipboard measurements. The results of the work in each of these areas is reported in separate sections of this report. Additionally, a section of this report has been devoted to describing the background conditions that make the results of this effort valuable and the significance that it has in producing more electromagnetically effective ships. An effort was also made to coordinate this effort with work that has been produced in the past by other government agencies and companies.

A final section of the report has the conclusions and recommendations based on the Phase 1 effort. An appendix has also been provided which contains the three interim reports submitted during the project.

2. SIGNIFICANCE OF THE BELOW DECK EME PROBLEM

Recent history concerning shipboard EMI cases shows problems resulting from high levels of RF energy below deck. The RF energy below decks is the result of transmitting equipments such as communication transmitters, radars and ECM equipment with antennas above deck and computers, machinery and associated control circuits found below deck. The most significant sources of interference have been HF communication transmitters and switches associated with machinery below decks. Victims of this interference have been found to be solid state low level monitoring circuits which normally operate in the 4 to 20 milliampere range at 24 VDC.

The United States Navy has developed effective prediction programs to describe the fields above deck from 1 MHz to high microwave frequencies. NAVSEA and NOSC have been involved in this development. The Navy has also developed programs for predicting the below deck fields and this has been very effectively accomplished by NUSC with the main application of these programs being for submarines. The frequency range for these models is from DC to 1 MHz.

The models developed in this effort interface these two programs. That is, the above deck prediction program from 1 MHz to microwave frequencies does not predict signal transfer to below deck spaces and the below deck program is confined to the prediction of radiated and conducted fields generated below deck only. The Comsearch model developed in this program predicts the field levels found below decks caused by above deck radiation or below deck radiation above 1 MHz. Below 1 MHz the NUSC program may be used for field predictions.

In the initial phase of this task, work has concentrated in the HF frequency range. This was done for a number of reasons. First, it extends the frequency capability of the NUSC program. Also, many present fleet problems are reported caused by HF. At VHF, UHF and microwave frequencies the coupling to the below deck areas is not of significant levels to produce a high number of EMI problems although some cases have been reported. Most of these cases involve cable penetration above deck. One notable example of this is the AN/SPS-43 radar which has caused below deck interference problems by cable and case penetration above deck.

HF interference has resulted in degrading interference to below deck systems on at least three new classes of U.S. Navy ships. They are the FFG-7, PHM and SNEP classes. There are also reports of HF interference causing degradation to the AN/SPS-40 radar cabinets via below deck coupling on the AN/SPS-40 radar cabinets on board the DD-963 class.

Because of these shipboard conditions, and to make the technical thrust of this contract more manageable, it was agreed to limit the frequency range of the effort to the HF range. It was also agreed to tailor the data effort so that it would fit the existing NUSC low frequency model requirements. The empirical data approach proposed was also modified to produce controlled experimental data that would provide a better description of the coupling path to the below deck areas. This modification from the original empirical approach has a significant effect on the data collection techniques. The controlled experiment approach means that automated data collection techniques cannot be utilized and that the level of the technical people performing the tests must be higher. In addition to the conducted and radiated field measurements, data will have to be recorded describing the complex coupling phenomenon. This will require not only technical skills and understanding by the measurement team but the verbal skills to precisely describe the signal transfer.

In addition to making the models and the measurement data compatible with the NUSC database, consideration for MIL-STD-461 limits and data formats will also be made. Based on previously measured data on board ships there are many locations below decks where MIL-STD-461 limits are exceeded. This may present a problem where equipments have undergone MIL-STD-461 and have "passed" but the environment in which they are then expected to function exceed the test limits. However, the worst cases will still be the large number of equipments in the U.S. Navy inventory used on board ships that have not undergone MIL-STD-461 testing or have had the requirements waived.

Another important description of ship below deck environment will be obtained from the data measured. That is, how does the environment vary for various classes of ships? The issue of whether certain classes of ships have much higher conducted and radiated levels below decks will be addressed. Ships that are built to MIL-STD-1310D will be compared to ships that are not from a below decks environmental standpoint. This not only has an EMI implication but an EMP consideration also.

3. MODEL SYNTHESIS TECHNIQUES

The computer methodology divides into four steps:

1. EM radiation by the topside HF emitters in a shipboard environment.
2. Transfer of energy to the topside cables.
3. Cable-to-cable coupling.
4. Re-radiation by the below decks cables into the interior of compartments.

At each step the appropriate computer models and databases are needed. The flow of the models is shown schematically in Figure 3-1.

Because of the nature of the shipboard EM environment, a solution to the problems of this task cannot be found with high accuracy with the current tools available. The EMC engineer must make approximations and place worst-case bounds on the models so that the analysis process is efficient. The following sections will discuss: 3.1 Assumptions in Model, 3.2 Input Required, 3.3 Description of Models, 3.4 Output Format, and 3.5 Problems Remaining To Be Solved.

3.1 Assumptions in Model

At this point in the development of the below decks coupling model, certain assumptions and/or approximations must be made. The resulting model will be a computer cull-type model. This may even be the goal in the long run due to the complexity of the physics involved.

It can be seen that these models fall into the general categories of field above-deck, antenna-to-cable transfer, cable-to-cable transfer, and cable re-radiation below deck.

Prediction of the above deck field from HF equipments is currently feasible (e.g. the NAVSEA SEMCA computer program). The propagation of EM energy from a whip above a ground plane is a standard textbook topic. Thus, this part of the modeling is well grounded in theory and has been implemented in the shipboard

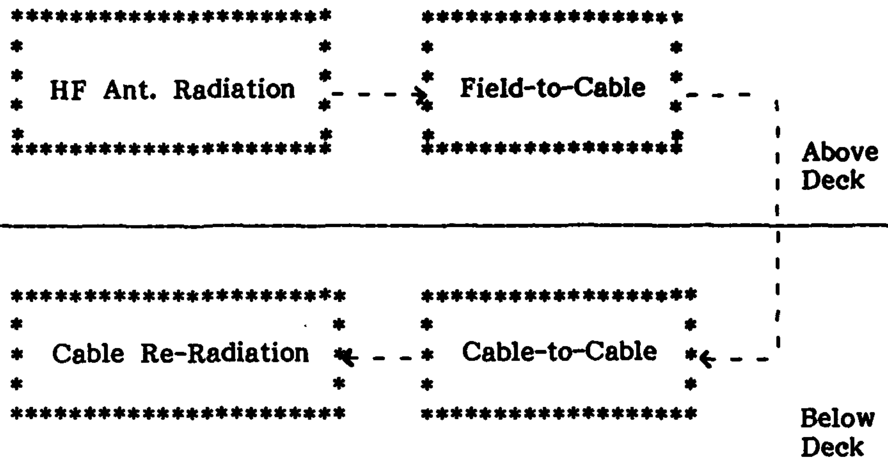

Figure 3-1 Flow Diagram of Computer Models

environment. The assumptions inherent in these existing r ~dels will be continued and improved where necessary. Some typical approximations used in a cull analysis are:

1. No reflections topside.
2. Ignore the effects of the superstructure.
3. Ignore intermodulation and spurious emissions.

The routing of the cables above deck being complex, the following alternative approximations are under consideration for this project:

1. The exposure length topside is not considered, set to a nominal value.

2. Assume cables are unshielded topside and run from deck to mast top perpendicular to deck over full length.

3. The topside transfer is not a function of angle.

The cable is characterized by the length and midpoint of its unshielded sections. These are necessary because it appears to be too difficult to define the cable accurately over its full length in terms of position and shielding. Even if this could be done the coupling to the cable would be difficult to calculate. The most promising compromise appears to be Option 3. The field would be calculated at the midpoint of the unshielded sections of the cable and the maximum found and used to determine the current developed in the cable.

The following are EM wave-to-cable assumptions being considered:

1. The primary mode of energy transfer to the cable is Ohm's law on the outer cable shield.

2. The inductive and capacitive coupling of the cable components (outer shield, inner conductors) and the adjacent cables or structures is considered.

While assumption 1 is used in the sample comparison of measured vs. predicted elsewhere in this report, further measurements and model development is expected in this area.

Cable-to-cable transfer models are already implemented in the existing software developed in this task, in the form of a cable type matrix and simple fall-off with distance calculations. The part of this model different for this project is the database giving the cable routing throughout the ship. Some of this data is tedious if not impossible to obtain. Thus the following approximations are being considered for this project:

1. All cables in a room are bundled together and pass through the room in a standardized manner (e.g. at the ceiling center). The inter-cable separation is defined by the diameters of the cables in the bundle. This a worst-case assumption.

2. The routing of cables below decks can be described by a list defining which cables are present in which rooms.

3. The routing of cables above deck is defined by a similar inter-cable separation matrix. This is the minimum distance.

4. The cable-to-cable transfer is independent of the length of the adjacency of the cables involved.

5. The level along the cable below decks is constant. This is a worst case assumption.

The cable re-radiation below decks is complicated by the fact that it is taking place in a box (the room) of arbitrary shape, size, and contents. The room is also usually smaller than the wavelength of the radiation. Thus the following approximations are being considered:

1. Peak of standing wave will be predicted.

2. The prediction will not consider any attributes of the room involved. Magnetic radiation by below decks cables is implemented in the current software. Electric field radiation at HF frequencies would be an added capability.

3.2 Input Required

The current software has an emitter database of level vs. frequency. The topside HF emitters should be added directly to this database if possible. They are different from the typical below deck emitter in that their output power is constant over their tuning range, although the radiated power changes depending on how the wavelength is matched to the antenna length. A database for the antennas and multicouplers is also necessary. These databases are ship-independent. The actual combinations of equipment used and the locations of the antennas will be input to the software as proposed in this project. At the beginning this data need not be exhaustive since the purpose of this project is not to develop this data. The completeness and amount of detail in these databases should increase as the entire model is proved by validation measurements.

Another necessary ship-independent input to this software is a matrix giving the separation between the HF emitters and the topside cables as shown in Figure 3-2.

The physical arrangement of the topside transmitters and cables is thus defined by a matrix giving the separation between each transmitter and the approximate center of the cable run topside.

The format for the cable routing below decks is simply a list of the cables entering each room without regard for the proximity of one cable to another. It is felt that the exact routing of cables in a room is too difficult to obtain and that the knowledge that the cable enters a room is enough for a cull analysis of the cable-to-cable transfer below decks. The cable will be assumed to be bundled together and thus separated by some nominal small value (i.e. cable diameter) to give a worst-case result. Standard nomenclature for the cables will be used if possible.

Shielding and grounding-collars effectiveness will be included in the analysis by an input of a loss value to reduce the current excited on the topside cable runs. This value will be constant over the frequency band of interest.

TX. NAME	Cable No.							
	1	2	3	4	5	6	7	8
URC-20	15.	13.	45.	33.	40.	44.	20.	21.
QRC-22								
WSC-6								
QRC-43								
SRA-21								

Figure 3-2 Data Input for Separation Matrix (Meters)

3.3 Description of Models

The first model needed in the analysis is one for the field strength at a point in space due to a topside HF emitter. Although complex models are available (NAVSEA, SEMCA, IEMCAP, etc.) and may be used in the future on this project, the following model was used as an example in this report.

$$E = 37.25 * I * (1 - \cos G)$$

where E = field strength at 1 mile (mv/meter)
I = current in antenna (amps)
G = electrical height of antenna (degrees)
(G = (360/k) *L where k is wavelength in meters and L is antenna length in meters.)

This equation results in a sinusoidal variation in the resulting field and as the wavelength approaches the length of the antenna the field drops off to zero. A correction factor is applied to this result to obtain the field at an arbitrary distance.

An Ohm's law model used for the transfer of the EM field onto the topside cable. In equation form this is:

V(mv) = E(mv/m) * cable length (meters)
I(ma) = V(mv) / cable resistance (ohms)

The model used for the re-radiation below decks is:

$$E2 = (I * L2 * 377) / (2 * R2 * k)$$

where
E2 = below deck electric field at a distance R2 from cable (mv/m)
I = current on cable (ma)
L2 = length of cable below decks (meters)
R2 = distance to measurement point (meters)
k = wavelength (meters)

A BASIC language listing of the program is shown in Figure 3-3.

Note: * = multiplication.

```
0010 DEF FNL(X)=LOG(X)/LOG(10)
2400 PRINT '1 ********** HF TO CABLE COUPLING MODEL ***********'
2401 PRINT ' ENTER ANTENNA CURRENT(AMPS):':
2402 INPUT IO
2403 PRINT ' ENTER ANTENNA LENGTH(METERS):':
2404 INPUT L
2405 PRINT ' ENTER DISTANCE FROM ANTENNA TO CABLE(METERS):':
2406 INPUT R1
2407 PRINT ' ENTER RESISTANCE OF CABLE(OHMS PER METER):':
2408 INPUT R
2409 PRINT ' ENTER LENGTH OF CABLE ABOVE-DECK(METERS):'"
2410 INPUT L1
2411 PRINT ' ENTER LENGTH OF CABLE BELOW-DECK(METERS):':
2412 INPUT L2
2413 PRINT ' ENTER DISTANCE FROM CABLE TO MEAS. POINT(METERS):':
2414 INPUT R2
2430 PRINT ' ENTER FLO,FHI(MHZ):':
2435 INPUT F1,F2
2439 PRINT TAB(10),'F(MHZ)':
2440 PRINT TAB(20):'E-AD(MV/M)':TAB(35):'I-MA':TAB(50):'E-BD(MV/M)'
2445 FOR F=F1 TO F2
2450 G=360*L*F/300
2455 E1=+37.25*IO*(1-FNC(G))*(1609/R1)
2460 V1=E1*L1
2465 I=V1/(R*L1)
2470 E2=(I*L2*377)/(2*R2*(300/F))
2480 PRINT TAB(10):F:TAB(20):E1:TAB(35):I:TAB(50):E2
2490 NEXT F
2491 PRINT 'ENTER 0 TO CONTINUE'
2492 INPUT X
2499 RETURN
```

Figure 3-3 BASIC Language Listing of HF-to-Cable Coupling Model

3.4 Output Format

The typical result from the above analysis is a plot of level vs. frequency for a specific measurement site in a below decks room. For static conditions of the HF emitters the plot would be expected to have peaks at the frequencies of these emitters. During validation the transmitter would be tuned across its band of operation while the measurements are taken. This type of measurement would show how a change in frequency affects different parts of the model.

3.5 Problems Remaining to Be Solved

All of the models will have approximations associated with them. This is the nature of the shipboard environment. It is just too complex to hope to obtain answers down to 5 decimal places. Often 10 or 20 dB errors can be tolerated if the results are considered by an intelligent engineer. All of the models discussed need to be carefully analyzed to obtain those which guarantee a reasonable accuracy along with efficiency of calculation.

At this point in the task one of the most difficult problems conceptually is to come up with an efficient method to define the topside cable runs for input to the computer models, due to the randomness of the paths they follow. Another problem area of the modeling is the field-to-cable coupling. It appears difficult to obtain simple models for the electric field coupling to the many different types of cable involved.

4. COMPARISON OF MODEL PREDICTIONS TO MEASURED DATA

In order to test the model synthesis technique both conducted and radiated data measured on the FFG-7 class were compared to the model predictions.

4.1 Radiated Field Data Above Deck

The first portion of the model predicts the radiated field at the above deck cable, pipe, structure, etc. This part of the program is extremely important in that its accuracy is the key to the accuracy of the below deck prediction of conducted and radiated level. The coupling to the below deck areas is via the current transfer from the above deck radiated field to the conductive item above deck. The current then propagates via the conductive item to the below deck areas as both a conducted level inducing currents in co-located conductors and producing a radiated field as a result of the conduction.

As part of a SEMCIP effort on the FFG-7 class in 1981, measurements were made of the radiated field at the Stabilized Glide Slope Indicator (SGSI) from the port transmit 35' whip antenna. The purpose of these measurements were to define the radiated field at the SGSI so that EMI fixes to the unit could be tested to the appropriate levels.

This data was compared to the model developed in this program and is shown in Table 4-1 and Figure 4-1. Table 4-1 shows not only the predicted radiated levels above deck but also the conducted levels on the SGSI cables going below deck and the radiated field in the FFG-7 port helicopter hangar 10 meters from the RF current carrying cables.

4.2 Radiated and Conducted Field Data Below Decks

Measurements were also made on the FFG-7 class to determine the below deck levels as part of a FEMR project in 1980 to determine what shielding was required to correct EMI problems on various below deck systems. This measured data was collected in various areas on the ship. The compartment housing the combat system computer and the AN/SPS-49 radar cabinets was one test point. For this area the AN/SKR-4 coaxial cable was identified as a prime coupler of

energy from high on the main mast of the ship through the deck into the ship's communication center through a bulkhead to the passageway on the 02 level, down to a passageway on the main deck into the computer and radar compartment. The measured radiated level in the compartment from the starboard whip is shown in Figure 4-2. The measured conducted level from the starboard whip is shown in Figure 4-3. Both figures also contain the model predictions for this area. Table 4-2 contains the parameters used for the prediction and contains the predicted above deck radiated field at the AN/SKR-4 cable, the conducted level on the cable in the compartment, and the radiated field in the compartment one meter from the cable.

Another measurement made on the FFG-7 class ship involved the FAN transmitting antenna. The radiated field levels were measured in the TACAN/AN/SPS-55 radar compartment. The TACAN coaxial and antenna control cables and the AN/SPS-55 waveguide were the main coupling sources into the compartment. The radiated field was measured at a one meter separation from the front of the TACAN antenna control cabinet. Figure 4-4 shows the predicted and measured curves for the radiated field. Table 4-3 contains the predicted radiated field levels above decks for the TACAN cables and AN/SPS-55 radar waveguide, the conducted levels on the cables and waveguide below deck, and the radiated levels in the compartment.

The final example of predicted below deck conducted levels involves a multiconductor transducer cable in the machinery area of the FFG-7 class ships. This cable does not appear above deck at all and so a special scheme had to be devised in the program to predict the level. A topside cable length of 0 meters causes the program to default so a length of .0001 meters was selected so the program would run. Also the separation distance from antenna to cable was selected as 1000 meters. The distance to the cable is also assumed but it is required to make the program run. Both of these inputs were selected to make the measured and predicted levels correlate as closely as possible. The results are shown in Figure 4-5. Also Table 4-4 shows the tabulation of radiated levels 1 meter from the cable along with the conducted levels on the cable.

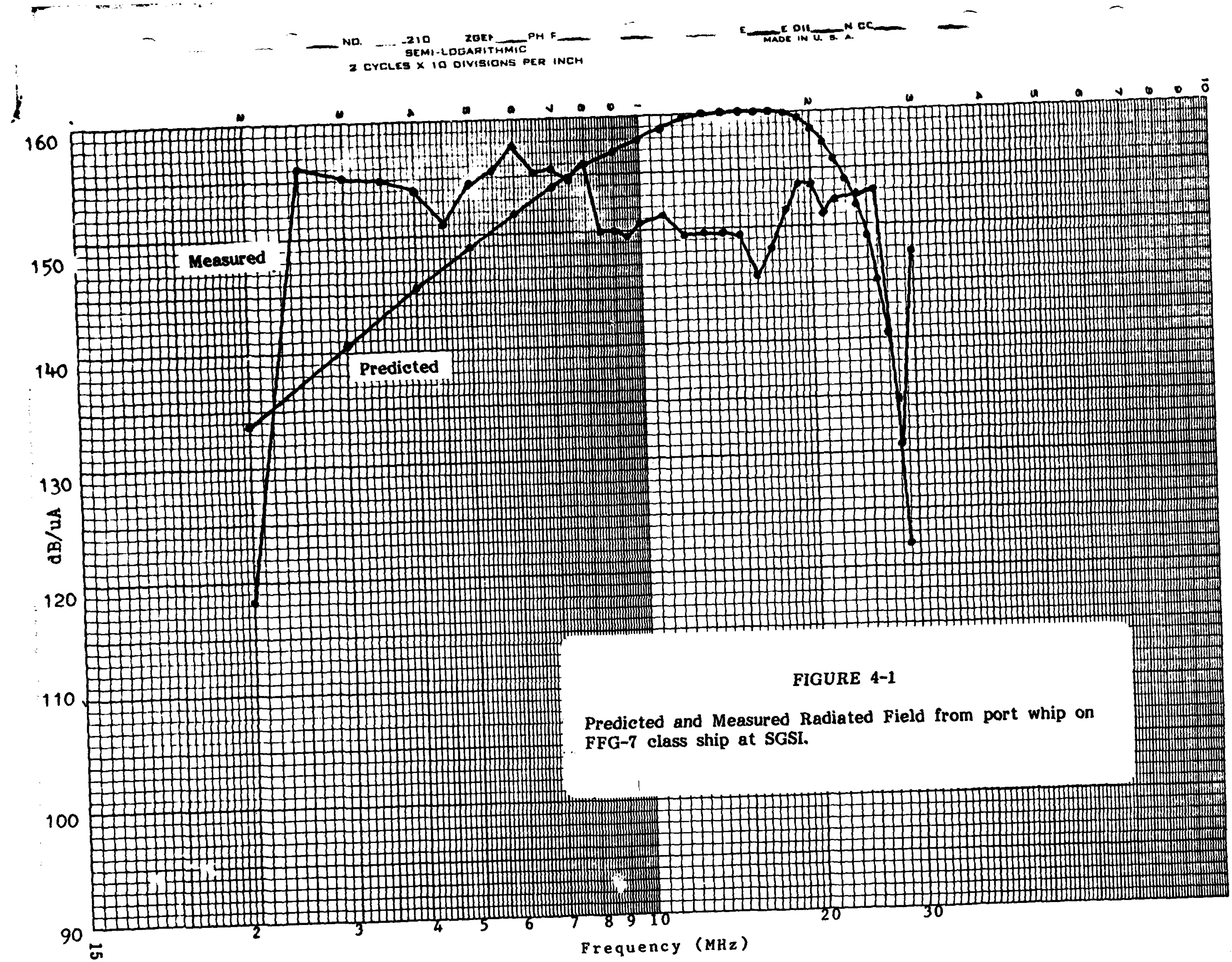

FIGURE 4-1

Predicted and Measured Radiated Field from port whip on FFG-7 class ship at SGSI.

```
********** HF TO CABLE COUPLING MODEL **********
ENTER ANTENNA CURRENT(AMPS): !14
ENTER ANTENNA LENGTH(METERS): !10
ENTER DISTANCE FROM ANTENNA TO CABLE(METERS): !15
ENTER RESISTANCE OF CABLE(OHMS PER METER): !1000
ENTER LENGTH OF CABLE ABOVE-DECK(METERS): !1
ENTER LENGTH OF CABLE BELOW-DECK(METERS): !25
ENTER DISTANCE FROM CABLE TO MEAS. POINT(METERS): !10
ENTER FLO,FHI(MHZ): !2
```

F (MHz)	Radiated Field Above Deck		Conducted Below Deck		Radiated Field Below Deck	
	MV/m	dB/uV/m	I-MA	dB/uA	MV/m	dB/uV/m
2	4836.25	133.6	4.83625	73.7	15.1939	83.6
3	10683.5	140.5	10.6835	80.5	50.3461	94.0
4	18508.7	145.3	18.5087	85.3	116.297	101.3
5	27969.8	148.9	27.9698	88.9	219.68	106.8
6	38653.4	151.7	38.6534	91.7	364.308	111.2
7	50092.4	153.9	50.0924	93.9	550.807	114.8
8	61786.9	155.8	61.7869	95.8	776.456	117.8
9	73225.9	157.3	73.2259	97.3	1035.23	120.3
10	83909.5	158.4	83.9094	98.5	1318.08	122.4
11	93370.6	159.4	93.3706	99.4	1613.37	124.2
12	101196	160.1	101.196	100.1	1907.54	125.6
13	107043	160.6	107.043	100.5	2185.91	126.8
14	110657	160.8	110.657	100.8	2433.53	127.7
15	111879	160.9	111.879	100.9	2636.15	128.4
16	110657	160.8	110.657	100.8	2781.17	128.8
17	107043	160.6	107.043	100.5	2858.49	129.1
18	101196	160.1	101.196	100.1	2861.3	129.1
19	93370.3	159.4	93.3702	99.4	2786.71	128.9
20	83909.1	158.4	83.9091	98.5	2636.15	128.4
21	73225.6	157.3	73.2256	97.3	2415.53	127.6
22	61786.5	155.8	61.7865	95.8	2135.24	126.5
23	50092	153.9	50.092	93.9	1809.78	125.1
24	38653	151.7	38.653	91.7	1457.22	123.2
25	27969.5	148.9	27.9695	88.9	1098.39	120.8
26	18508.5	145.3	18.5084	85.3	755.915	117.5
27	10683.3	140.5	10.6833	80.5	453.106	113.1
28	4836.09	133.6	4.83609	73.7	212.708	106.5
29	1222.35	121.7	1.22235	61.7	55.6829	94.9

TABLE 4-1

Predicted Field Levels to the SGSI from the Port Transmit Whip Above and Below Decks on the FFG-7 Class

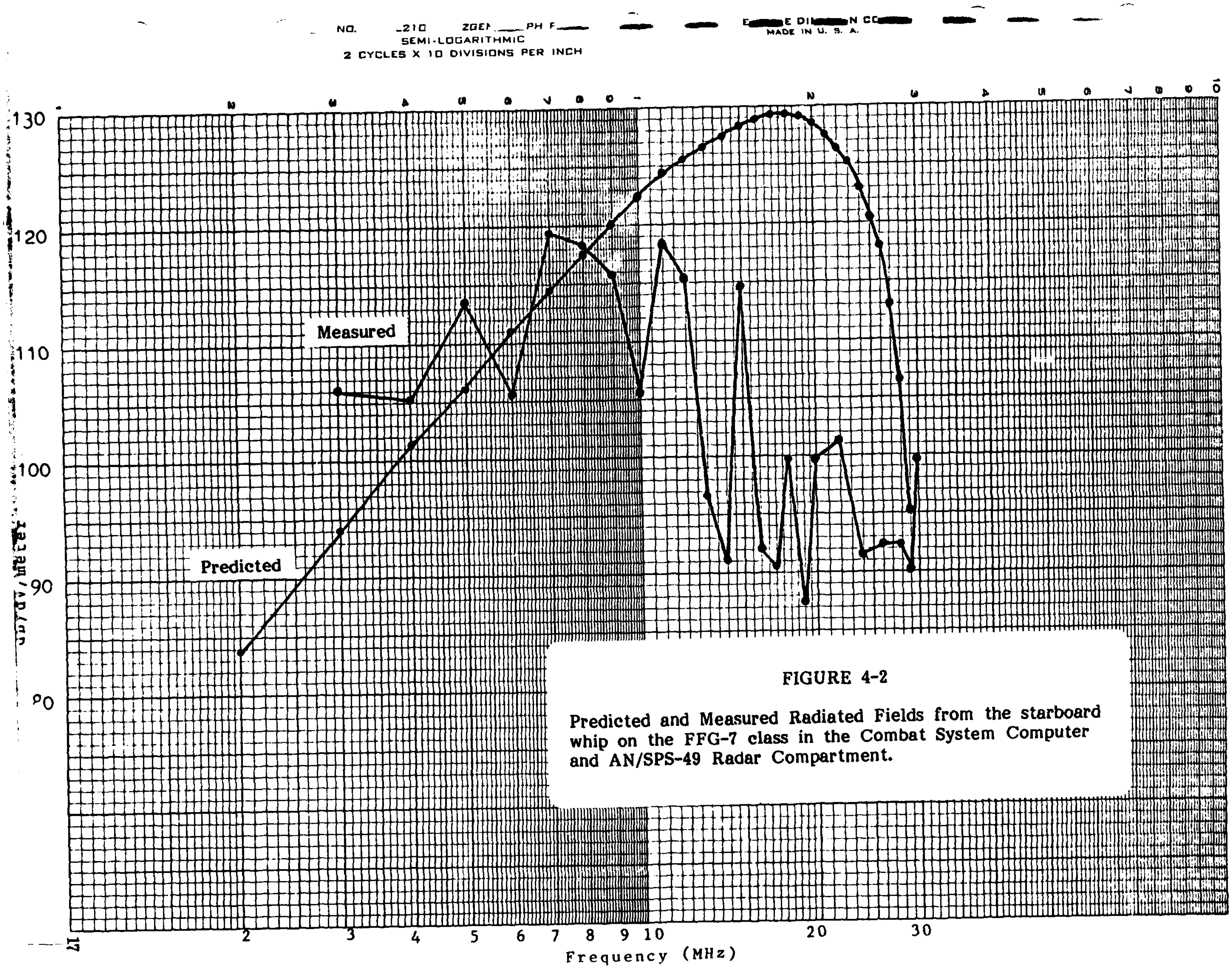

FIGURE 4-2

Predicted and Measured Radiated Fields from the starboard whip on the FFG-7 class in the Combat System Computer and AN/SPS-49 Radar Compartment.

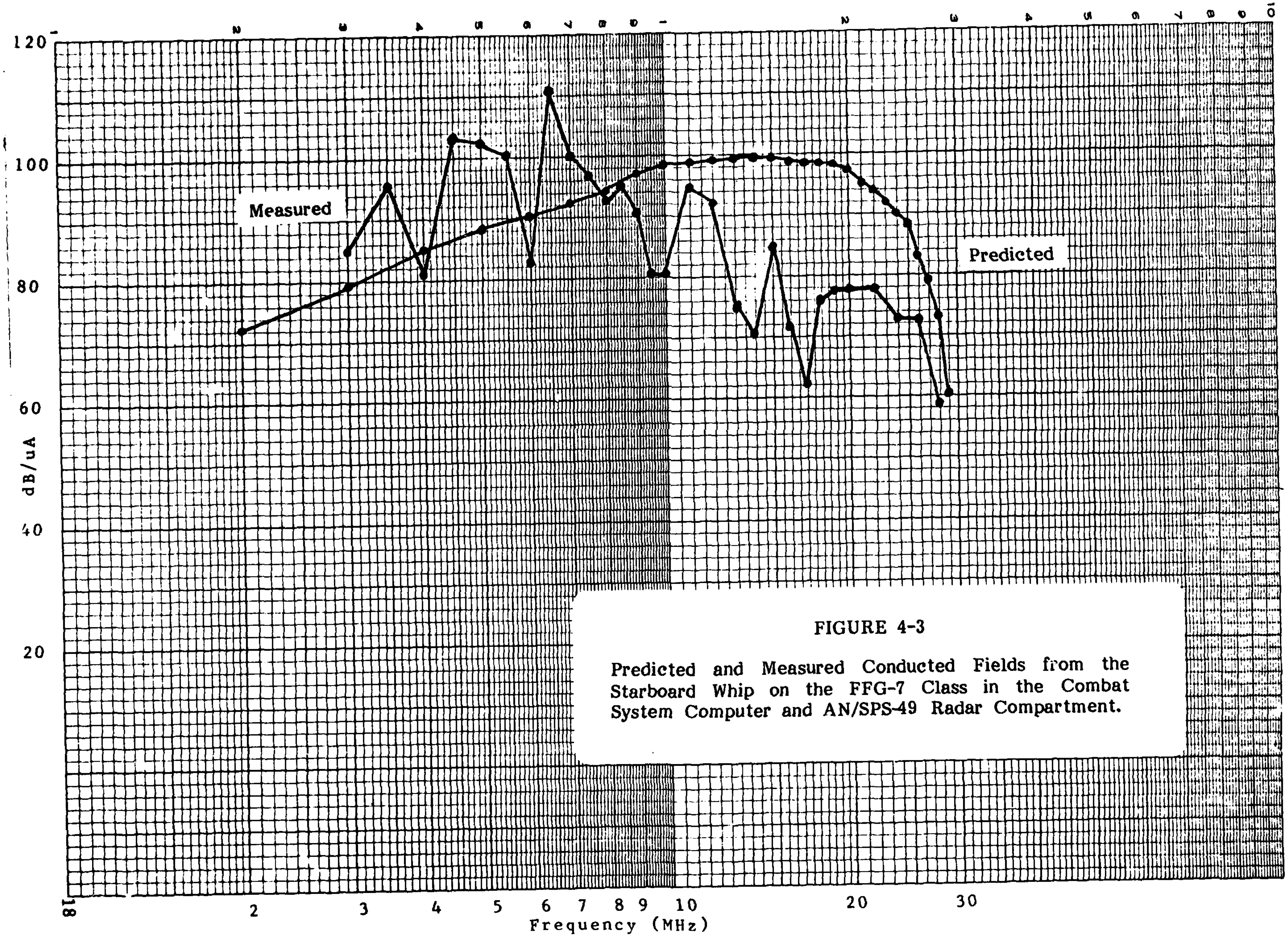

FIGURE 4-3

Predicted and Measured Conducted Fields from the Starboard Whip on the FFG-7 Class in the Combat System Computer and AN/SPS-49 Radar Compartment.

```
********** HF TO CABLE COUPLING MODEL **********
ENTER ANTENNA CURRENT(AMPS): !14
ENTER ANTENNA LENGTH(METERS): !10
ENTER DISTANCE FROM ANTENNA TO CABLE(METERS): !18
ENTER RESISTANCE OF CABLE(OHMS PER METER): !1000
ENTER LENGTH OF CABLE ABOVE-DECK(METERS): !36
ENTER LENGTH OF CABLE BELOW-DECK(METERS): !3
ENTER DISTANCE FROM CABLE TO MEAS. POINT(METERS): !1
ENTER FLO,FHI(MHZ): !2
```

F(MHz)	Radiated Field Above Deck	Conducted Field Below Deck		Radiated Field Below Deck	
	MV/m	I-MA	dB/uA	MV/m	dB/uV/m
2	4030.21	4.03021	72.1	15.1939	83.6
3	8902.95	8.90294	78.9	50.3461	94.0
4	15424	15.424	83.8	116.297	101.3
5	23308.2	23.3082	87.3	219.68	106.8
6	32211.1	32.2111	90.2	364.308	111.2
7	41743.7	41.7436	92.4	550.807	114.8
8	51489.1	51.4891	94.2	776.456	117.8
9	61021.6	61.0216	95.7	1035.23	120.3
10	69924.5	69.9245	96.8	1318.08	122.4
11	77808.8	77.8088	97.8	1613.37	124.2
12	84329.8	84.3298	98.5	1907.54	125.6
13	89202.5	89.2025	99.0	2185.91	126.8
14	92214	92.214	99.3	2433.53	127.7
15	93232.6	93.2326	99.4	2636.15	128.4
16	92213.9	92.2139	99.3	2781.17	128.8
17	89202.3	89.2023	99.0	2858.49	129.1
18	84329.6	84.3296	98.5	2861.3	129.1
19	77808.5	77.8085	97.8	2786.71	128.9
20	69924.3	69.9243	96.9	2636.15	128.4
21	61021.3	61.0213	95.7	2415.53	127.6
22	51488.8	51.4888	94.2	2135.24	126.5
23	41743.3	41.7433	92.4	1809.78	125.2
24	32210.8	32.2108	90.2	1457.22	123.2
25	23307.9	23.3079	87.3	1098.39	120.8
26	15423.7	15.4237	83.8	755.916	117.5
27	8902.77	8.90277	78.9	453.106	113.1
28	4030.08	4.03008	72.1	212.708	106.5
29	1018.62	1.01862	60.0	55.6829	94.9

TABLE 4-2

Predicted Field Levels to the Computer and Radar Compartment Area from the Starboard Whip on the FFG-7 Class

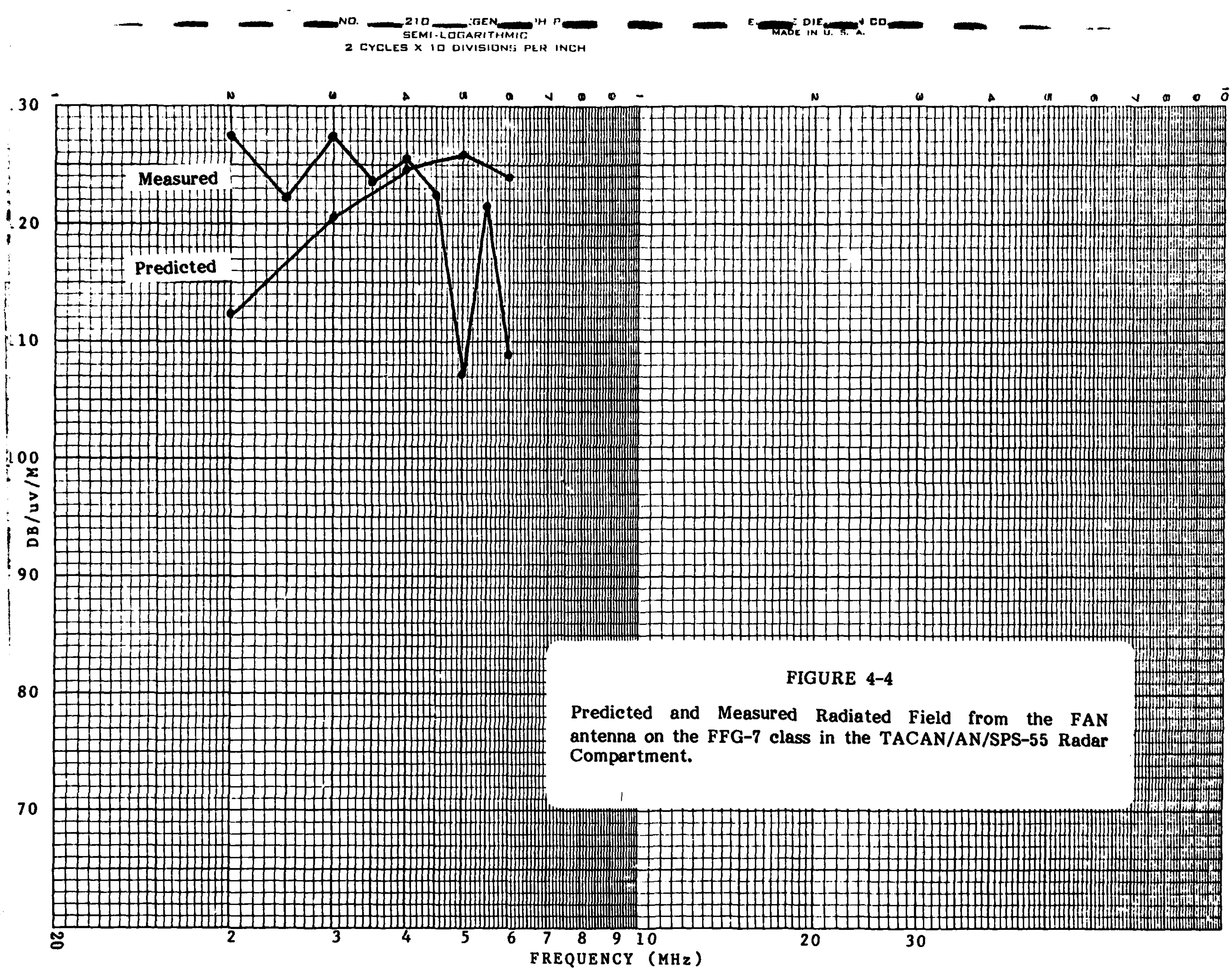

FIGURE 4-4

Predicted and Measured Radiated Field from the FAN antenna on the FFG-7 class in the TACAN/AN/SPS-55 Radar Compartment.

```
********** HF TO CABLE COUPLING MODEL **********
ENTER ANTENNA CURRENT(AMPS): !7
ENTER ANTENNA LENGTH(METERS): !36
ENTER DISTANCE FROM ANTENNA TO CABLE(METERS): !3
ENTER RESISTANCE OF CABLE(OHMS PER METER): !600
ENTER LENGTH OF CABLE ABOVE-DECK(METERS): !36
ENTER LENGTH OF CABLE BELOW-DECK(METERS): !1.5
ENTER DISTANCE FROM CABLE TO MEAS. POINT(METERS): !1
ENTER FLO,FHI(MHZ): !2
```

F(MHz)	Radiated Field Above Deck	Conducted Field Below Deck	Radiated Field Below Deck	
	MV/m	I-MA	MV/m	dB/uV/m
2	131068	218.447	411.772	112.2
3	228992	381.654	1079.13	120.6
4	278595	464.325	1750.51	124.8
5	252989	421.648	1987.02	125.9
6	166054	276.756	1565.05	123.8

TABLE 4-3

Predicted Field Levels to the TACAN/AN/SPS-55 Radar Compartment from the FAN Antenna on the FFG-7 Class.

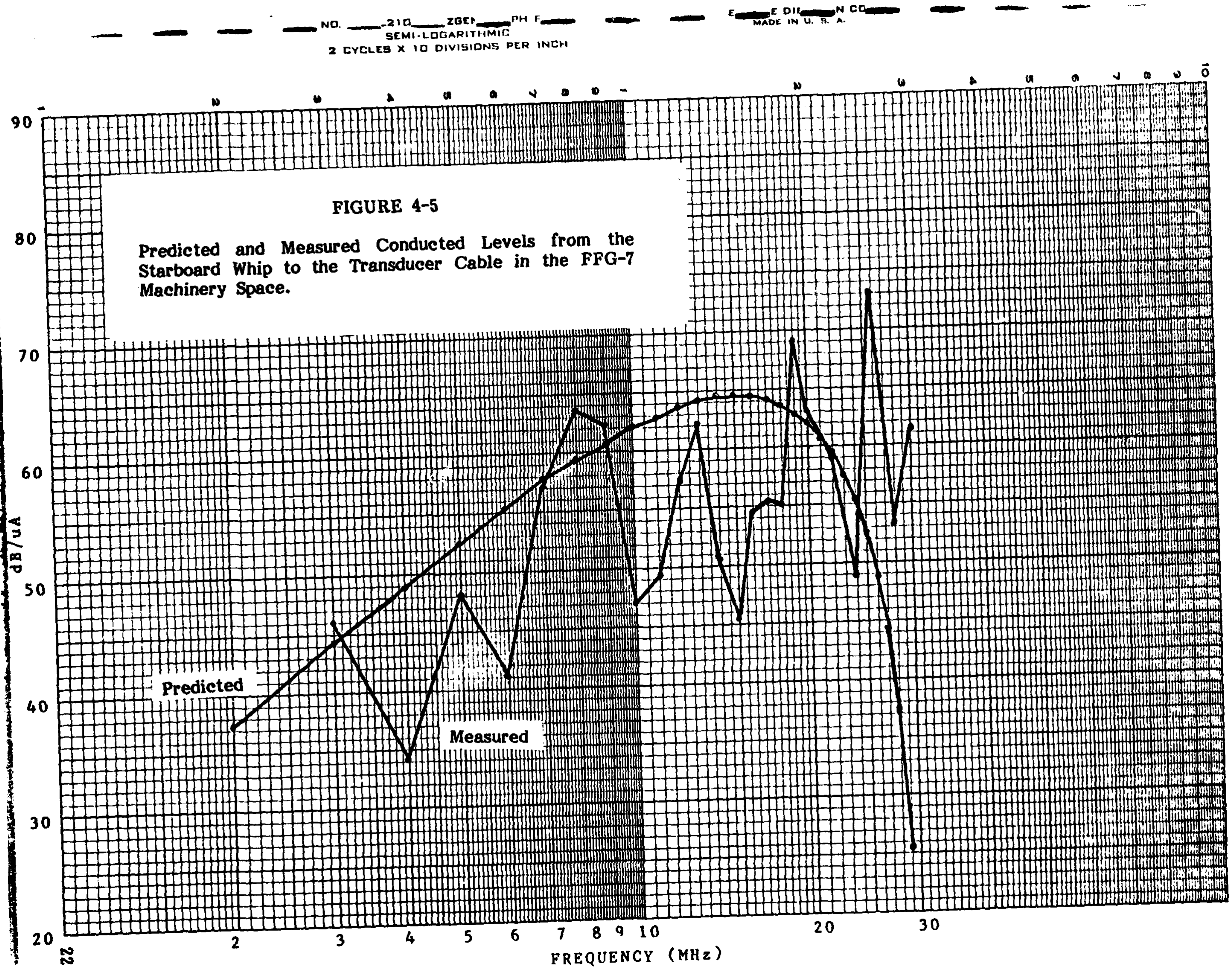

FIGURE 4-5

Predicted and Measured Conducted Levels from the Starboard Whip to the Transducer Cable in the FFG-7 Machinery Space.

********** HF TO CABLE COUPLING MODEL **********

ENTER ANTENNA CURRENT(AMPS): !14
ENTER ANTENNA LENGTH(METERS): !10
ENTER DISTANCE FROM ANTENNA TO CABLE(METERS): !1000
ENTER RESISTANCE OF CABLE(OHMS PER METER): !1000
ENTER LENGTH OF CABLE ABOVE-DECK(METERS): !.0001
ENTER LENGTH OF CABLE BELOW-DECK(METERS): !1.5
ENTER DISTANCE FROM CABLE TO MEAS. POINT(METERS): !1

F(MHz)	Radiated Field Above Deck	Conducted Field Below		Radiated Field Below Deck
	MV/m	I-MA	dB/ua	MV/m
2	72.5437	.0725437	37.3	.136745
3	160.253	.160253	44.1	.453115
4	277.631	.277631	48.8	1.04667
5	419.548	.419548	52.5	1.97712
6	579.801	.5798	55.3	3.27877
7	751.386	.751386	57.5	4.95726
8	926.804	.926804	59.3	6.9881
9	1098.39	1.09839	60.8	9.31709
10	1258.64	1.25864	62.0	11.8627
11	1400.56	1.40056	62.9	14.5203
12	1517.94	1.51794	63.6	17.1679
13	1605.65	1.60565	64.1	19.6732
14	1659.85	1.65985	64.4	21.9017
15	1678.19	1.67819	64.5	23.7254
16	1659.85	1.65985	64.4	25.0305
17	1605.64	1.60564	64.1	25.7264
18	1517.93	1.51793	63.6	25.7517
19	1400.55	1.40055	62.9	25.0804
20	1258.64	1.25864	62.0	23.7253
21	1098.38	1.09838	60.8	21.7398
22	926.798	.926798	59.3	19.2172
23	751.38	.75138	57.5	16.288
24	579.795	.579795	55.3	13.115
25	419.543	.419543	52.5	9.88548
26	277.627	.277627	48.8	6.80324
27	160.25	.16025	44.1	4.07796
28	72.5414	.0725414	37.3	1.91437
29	18.3352	.0183352	25.2	.501146

TABLE 4-4

Predicted Radiated and Conducted Levels to the Engine Room from the Starboard Whip on the FFG-7 Class.

5. MEASUREMENT TECHNIQUES

5.1 Background

The purpose of the measurements to be performed on board ship is to provide data to allow for a better understanding of the below decks electromagnetic conducted and radiated environment. This understanding should be fleetwide so that various classes of ships may be measured. Implicit in this understanding is that the coupling mechanism would be described both physically and mathematically. Once the coupling mechanism can be explained and modeled mathematically the prediction process for conducted and radiated fields can be developed and used for the determination of compatible operation of equipments in various spaces in below deck areas of ships.

Initially an empirical approach was envisioned for the development of models for predicting below deck levels but after a number of meetings with various experts in the electromagnetic compatibility field the need for understanding the coupling mechanism of the signals had the highest priorty. Therefore, it was suggested that the empirical approach be de-emphasized in favor of data collection with a detailed coupling path description. Whereas the empirical approach lends itself to automated measurements, the measurement and description of the coupling path does not. Therefore automated techniques may have to be confined to data storage and analysis. Data collection instrumentation will have to be non-automated because of the requirement of determining peak levels and the tracing of coupling paths.

5.2 Measurement Conditions

Ship drawings will be examined to determine the number of test points required for a class of ship. A ship will be divided into below deck zones. Zones will be a function of separation from bulkheads that are weatherdeck boundaries and cables, pipes and other conductive structures that penetrate the zone space and also appear above deck. The nature of the deck penetration is also a factor in determining the test points to be measured.

Twenty test zones will be selected for both radiated and conducted measurements. Each test zone will have a unique physical feature. That is, it will have different deck penetrations (or none), have an RF suppression technique (or none) used where the cables, pipes or other conductive structure penetrates the zone and will have a different ship function.

All measurements will be performed across the frequency range of the HF transmitting antennas on the ship and these will serve as a radiating source with the frequency interval 0.5 MHz from 2 to 10 MHz; 1 MHz from 10 to 20 MHz; and 2 MHz from 20 to 30 MHz.

5.3 Data Collection

At each test zone both conducted and radiated levels will be measured. For the radiated level the test antenna used will be moved in the test zone to determine the peak level for that frequency. This level will be recorded. The conducted level will be measured at a fixed point.

The measurement zone will be photographed. At each frequency a magnetic probe will be used to determine the coupling path of the signal into the zone. This path will be described verbally and where helpful photographs will be taken of the path to supplement the description. For a zone the coupling path may not change with frequency or transmit antenna. However, a check of this condition will be made at each frequency.

The plan to gather data will allow entry of the measured and recorded data into the NUSC database. The plan is to divide the ship into several zones and make extensive measurements in these zones, identify the special entry points of RF energy and model the data so that predictions may be extended to areas where no measurements were made.

5.4 Instrumentation

The measurement of the radiated and conducted levels will be accomplished using a Tektronix 492P spectrum analyzer controlled with a measurement computer like the Hewlett Packard 9828. The storage capability, both display

and data, of the analyzer will be utilized. Photographs of the display of the analyzer will provide a quick output of the amplitude versus frequency characteristic. The data will also be recorded on cassette tape for later play back on an X-Y recorder and fed to the company computer for further analysis.

Pick up devices to be used on board the ship will be standard test antennas, current probes and a magnetic probe. The calibration factor of the test antenna and current probe will be recorded in the measurement computer so that the data measured on board ship will be reduced to the proper field dimensions of dB/μv/meter for the radiated measurement and dB/μa for the conducted measurement. There will be no need to enter the calibration factor or the magnetic probe as it will be used for signal path tracing only to determine coupling paths.

Photographic techniques will be used extensively for data collection. A scope camera will be used to record the spectrum analyzer display and a 35mm camera the zones of measurement and the shipboard conditions.

To keep weight to a minimum, the shipboard teams will take five cases of equipment on board ship with them. One case will have the spectrum analyzer, the second the measurement computer, the third the photographic equipment, the fourth the interconnect cables, connectors, attenuators and miscellaneous devices and the fifth the antennas and probes.

5.5 Procedures

Measurements will be performed with a minimum of impact on the ship. For each test point radiation from each of the shipboard antennas will be cycled from the lowest to the highest frequency for the frequency intervals specified. Radiation need not be limited to the antenna under test but care must be taken not to violate frequency management plans as test signals are radiated.

For each frequency the conducted level will be measured first and recorded on the spectrum analyzer A channel. Next the B channel operated in peak level will receive the radiated level. The test antenna will be moved throughout the zone until the peak signal is obtained. This level will be recorded. The position

where this occurs will be recorded. Next the magnetic probe will be connected and the zone examined to determine the coupling path of the signal into the compartment. This will be described on the data sheet. The photograph of the A and B channel of the spectrum analyzer with the scope camera will not be made until all of the frequencies for an individual antenna is complete. At this time the data will be put on the cassette also. Photographs of coupling path will be made at least once for each zone using the 35mm camera. If significant changes occur with frequency then additional photographs will be made. Photographs at each test zone showing the conducted test point and the initial radiated measurement test point will also be made.

The shipboard transmitter will be operated in CW mode and set for 1 kW. A transmitter data sheet will be kept in the communications center recording the power output at each frequency. Communications between the test zone and the communications center will be over either the ships IMC or walkie-talkies.

5.6 Support Data

In order to produce the most complete package of data, certain supporting data items must be recorded. These include transmitting antenna type, transmitter, cable identification, compartment number, separation distance between antenna and topside structure providing coupling path to the below deck area (this can be done in matrix form). Also, list all cables in each compartment which is a test zone, cable separation in each compartment, length of cables in the compartment, length of topside structure and cable function and type; that is, coaxial, power, multiconductor shielded etc.

6. OVERALL TASK PLAN FOR PHASE 2 EFFORT

6.1 Phase 2 Purpose

The purpose of the Phase 2 effort is to produce electromagnetic prediction models for the below deck areas for at least two ship classes for the HF frequency range. The technical effort in the Phase 2 work will concentrate on shipboard data collection. In addition to the measured conducted and radiated fields an attempt will be made to characterize the coupling mechanism for the energy. It is expected that the results of the investigation of this phase will have a profound effect on both the MIL-STD-461B limits for various equipments to be placed in the below deck areas of ships and MIL-STD-1310D which describes shielding, bonding and grounding of above deck items that will influence the coupling of energy to the below deck spaces. The other major effort in Phase 2 will be the development and refinement of a prediction model for below deck energy which was initiated in Phase 1.

6.2 Manpower Requirements

It is anticipated that the total time for the Phase 2 effort will be 18 months. In that time the following categories of work effort will be expended.

Labor Category	Hours
Principal Engineer	1000
Senior Engineer	1500
Engineer Analyst	1500
Technician	2000
Typist	200

6.3 Ship Trips

There are two classes of ships that will be investigated in the Phase 2 effort. They are the FFG-7 and DD-963 class. Access to the ships will be made in conjunction with the NAVSEA SEMCIP program when Phase II and III shipboard efforts are scheduled. It is hoped that twelve ship trips will be scheduled during

the Phase 2 effort. One half of the trips will be on FFG-7 class ships and the other half on DD-963 class ship. Scheduling will be through the SEMCIP coordinators for these two classes. The coordinators will be briefed at the start of the project and a schedule for the 12 month period obtained. The Phase 2 work will supplement the SEMCIP shipboard effort. The Phase 2 team will consist of two men who will operate in cooperation with, but independent of, the SEMCIP effort. They will be responsible to fit their activity into the SEMCIP schedule and to report directly to the SEMCIP shipboard coordinator. Each ship trip will take a period of 5 days which is the length of time required to complete a SEMCIP Phase II and Phase III effort.

6.4 Categories of Effort

The technical efforts in the Phase 2 effort fall into three major categories: Ship Trips, Data Analysis and Model Synthesis, and Technical Reports.

The ship trips will be to two ship classes with six ships of the class visited. The two ship classes are the FFG-7 and DD-963. The ship trips will be accomplished in the first year of the task so that the last six months can be devoted to model refinement and technical report preparation.

Data analysis and model synthesis will begin as soon as the first ship trip is complete. Analysis of signal coupling paths will be studied during this period so that techniques to describe the phenomenon can be developed. Various modeling techniques will be tested during this period to develop an optimum mathematical prediction program based on the data.

During the last six months of the task the below deck model will be refined to produce the most accurate representation of the data collected. Coupling path analysis will be an important aspect of this effort. A technical report describing all of the work in the task will be prepared at this time also. Interim reports and briefings as requested by the contracting engineer will be submitted during the term of the task.

6.5 Coordination of Task Work

In order to carry out the work of this contract, coordination will be necessary with a number of U.S. Navy activities. These activities are the NAVSEA sponsors, NUSC, NOSC, NAVSEA-SEMCIP, and NAVELEX.

Interim reports and close contact will keep the NAVSEA sponsor informed of the progress of the Phase 2 effort. The good communication link that was established during the Phase 1 work will be continued.

Coordination with NUSC and NOSC is important in that the Phase 2 work fits between the models developed by these two activities. Technical contacts at these organizations have been established during the Phase 1 work and will continue in Phase 2.

The NAVSEA-SEMCIP program plays an important role in the Phase 2 effort. It provides the access to the fleet that is absolutely necessary to the successful accomplishment of the technical goals of the work. The technical people assigned to this contract are also active in the SEMCIP program and are familiar with the standard operating procedures of the SEMCIP shipboard work.

Coordination with NAVELEX will be in the MIL-STD-461B and 1310D specifications that may be affected by the Phase 2 effort. Limits used in 461B and shielding, bonding and grounding prescribed by 1310D may be altered based on the results of Phase 2.

6.6 Event Schedule

Figure 6-1 shows the event schedule for the Phase 2 effort. The overall task will take eighteen months to complete. The shipboard measurement work will be completed in the first twelve months. Data analysis will begin after the first ship trip and continues into the thirteenth month of the contract. Model synthesis and prediction model refinement will be carried out from the fourth month to the seventeenth month of the contract. The final technical report will be written in the last six week period of the contract.

6.7 Personnel

The personnel who worked on the Phase 1 effort will serve as the nucleus for the Phase 2 effort. The same project manager and data analyst will be assigned to the work. In addition, personnel who are familiar with shipboard measurements and instrumentation will be active in this phase of the work.

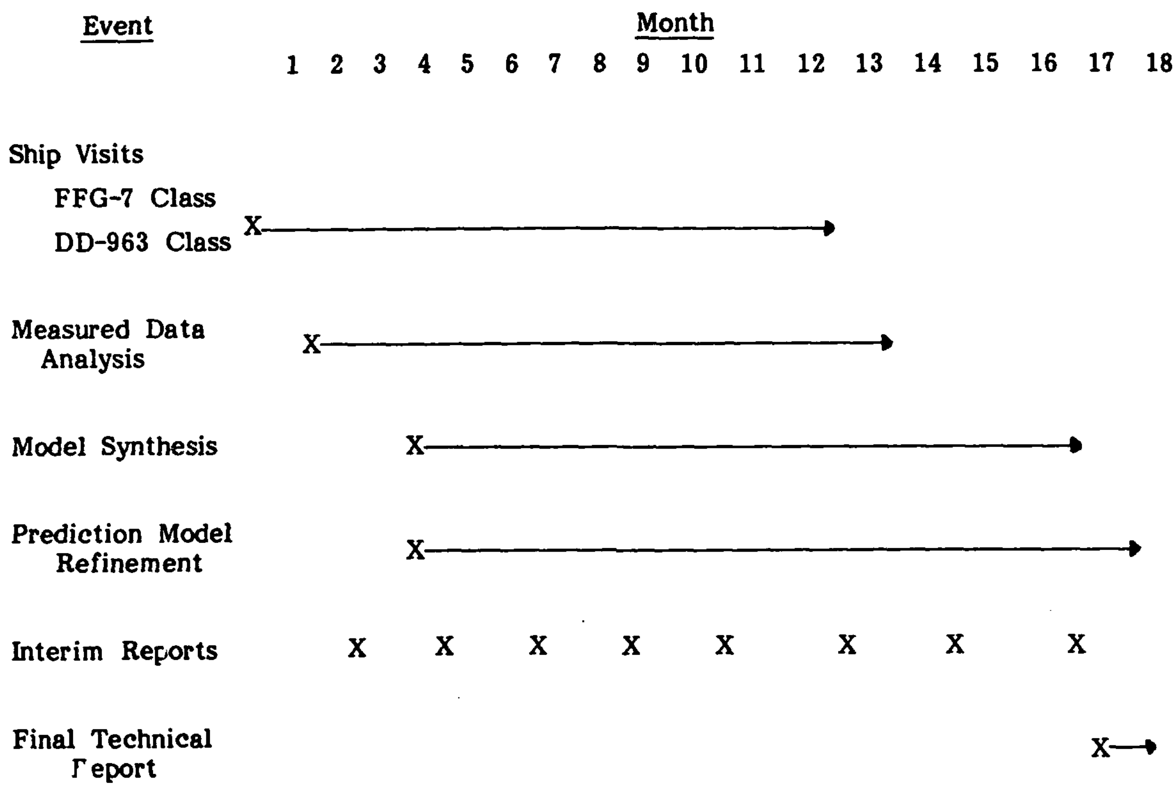

Figure 6-1 EVENT SCHEDULE FOR PHASE 2 EFFORT

7. TEST PLANS FOR THE FFG-7 AND DD-963 CLASS

The purpose of the test plans is to provide a step-by-step guideline to the test team personnel performing the measurements. A secondary usage of the test plans is as a handout to ship's personnel and other interested parties so that a clear understanding of the team's shipboard activity and needs of ship's services is communicated. Shipboard measurements will be in conjunction with SEMCIP Phase II and III activities so the test plan will always be provided to the SEMCIP ship coordinator. Figure 7-1 shows a sample cover sheet for the test plans to be used. The following pages contains the text material that will appear in the test plan.

7.1 Purpose of Measurements

The purpose of the measurements outlined in this test plan is to produce a set of data that will characterize the radiated and conducted electromagnetic HF fields in the below deck areas of ships. It will also identify the method of coupling of energy to the below deck areas from the topside or from different areas below deck. This test plan describes the resources required, test points and zones, test conditions, procedures, sequence of tests, data collection techniques and data sheets.

7.2 Test Resources

Two people will make up the test team. It will be necessary to use a ship's radio operator to sequence the transmitter through the frequency range on the proper antennas. The test team will communicate with the radio operator over the ships' IMC or walkie talkies. One team member will be designated test director and he will be responsible for communicating the test conditions.

It is estimated that it will take four hours to cycle through the frequency range of 2 to 30 MHz in the increments required if automatic tuning couplers such as the CU-938s are available. If the fan antennas are used two hours are required to cycle through the frequency range of 2 to 6 MHz in the increments required.

Test Plan

for

Electromagnetic Environment Measurements

on the

U.S.S. (   )   FFG-(   )

DD -(   )

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FIGURE 7-1   Test Plan Cover Sheet

By using redundant test equipment simultaneous testing can be performed for multiple test zones. This will expedite the data collection on each ship trip. However, if only single items are available, it will be possible to measure four zones on the FFG-7 and two zones on the DD-963 class for each trip.

During the testing it will not be necessary for the ship to cease normal operation of their HF equipment. However, it will be necessary to know what circuits are active or are assigned so that if these frequencies are used during the tests the team can avoid recording erroneous data.

7.3 Test Zones

The following is a list of the twenty test zones selected on the FFG-7 and DD-963 class ships.

Test Zone	Description
1	CIC
2	Bridge
3	Main Engine Room
4	Port Helicopter Hangar
5	Starboard Helicopter Hangar
6	ECM Equipment Compartment
7	Central Control Console Compartment
8	AN/SPS-40(DD-963), AN/SPS-49(FFG-7) Compartment
9	MK-86(DD-963), MK-92(FFG-7) Compartment
10	Sonar Equipment Compartment
11	IC Compartment
12	Central Passageway AFT
13	Communication Center
14	TACAN Compartment
15	Auxiliary Machinery Room - 1
16	Auxiliary Machinery Room - 2
17	Electrical Distribution Switch Area
18	400 Hz Generator Area
19	NSSMS(DD-963), CIWS(FFG-7) Compartment
20	Navigation Compartment

For each trip not all zones will be measured. The number of zones that can be measured per ship trip is a function of the redundant test instruments available. For the FFG-7 class for the six trips scheduled for the task all twenty zones will be measured even if no redundant test equipment is available. However, for the DD-963 class only twelve zones will be measured in the six planned trips unless additional test instruments are used. The redundant test equipment will allow for completion of all the test zone data listed for the DD-963 and will also allow for multiple samples of the same zone.

Each test zone will be completely described as to compartment number, cables entering and leaving and position on the ship. Photographs, ships drawings and sketches will be used to describe the areas.

7.4 Test Instruments

The instruments to be used on the ship measurements will be:

Instrument	Manufacturer	Model #
* Spectrum Analyzer	Tektronix	492B
Mini Computer	Hewlett-Packard	9828
X-Y Recorder	Hewlett-Packard	7044B
* Antenna	Antenna Research	AVW-1/C
* Current Probe	Solar	6741-1
* Magnetic Probe	EMCO	7604
Scope Camera	Tektronix	C-5C
35 mm Camera	Cannon	AE-1
Cables, Attenuators and Connectors		

* More than one item will allow more than one zone to be measured at a time.

7.5 Test Procedures

The test equipment will be set up in an area where a single or multiple test zones can be monitored. For each test frequency the conducted and radiated

level in the zone will be measured and stored on the spectrum analyzer display and computer memory. For the radiated level measurement, the peak level in the zone will be found by moving the test antenna until the peak is found. The peak hold mode of the analyzer will be utilized for this position scan. The position for the peak will be described on the data sheet. Next the magnetic probe will be used to determine the entry or coupling path into the zone. When the frequency span is complete for the transmit antenna the spectrum analyzer display will be photographed and the data recorded on cassette tape. These data recordings will supplement the tabular data sheets that will be used.

Calibration of the spectrum analyzer will be accomplished using internal calibration signals. The internal calibration signal will be checked against secondary standards in the Comsearch Laboratory before and after each ship trip. The frequencies to be utilized will cover the entire HF frequency range from 2 to 30 MHz. When the FAN antenna is used the frequency range will be 2 to 6 MHz. The incremental steps will be 0.5 MHz. When the whip antennas are used the frequency range from 20 to 30 MHz will be covered. The incremental steps shall be 0.5 MHz from 2 to 10 MHz; 1 MHz from 10 to 20 MHz; and, 2 MHz from 20 to 30 MHz. For each frequency the transmitters will be operated in the CW mode with a 1 kW output continuously keyed by the crew member in radio central. A record of the forward and reflected power at each frequency will be made.

7.6 Test Sequence

The test sequence will be from low to high frequency. Antennas will be tested by position, forward antennas and starboard antennas given precedence. Where possible, antennas will be cycled in frequency together to rate the tuning time but this will require multiple pieces of test equipment.

Testing in the zone will be done in the following order, conducted measurement first, radiated measurement second and coupling measurement last. When these measurements are complete, the next test frequency will be set up and measured.

7.7 Data Sheets

The data sheets to be used are shown on the following pages. Data collection will be made on these tabular data sheets and by using photographic and magnetic tape recordings of the spectrum analyzer display. The data collection using these two techniques duplicate one another but will come in handy if automated data reduction and analysis techniques are used in the model synthesis work in this task.

TRANSMITTER STATUS LOG

Date: ____________________ Ship: ____________________

TIME	TRANSMITTER NUMBER	FREQUENCY (MHz)	ANTENNA	POWER OUTPUT Watts	
				Forward	Refl.

Table 7-1 Transmitter Data Sheet

CONDUCTED RECEIVE LEVELS

Ship: ______________________ Date: ______________________

Test Zone: ______________________ Team: ______________________

Cable Tested: ______________________ Transmit Antenna: ______________________

Transmit Frequencies (MHz)	Receiver Reading (dB/µV)	Probe Factor (dB/ Ω)	Current on Line (dB/ µa)	Time	Remarks
2.0					
2.5					
3.0					
3.5					
4.0					
4.5					
5.0					
5.5					
6.0					
6.5					
7.0					
7.5					
8.0					
8.5					
9.0					
9.5					
10.0					
11.0					
12.0					
13.0					
14.0					
15.0					
16.0					
17.0					

Table 7-2 Conducted Measurement Data Sheet

CONDUCTED RECEIVE LEVELS

Ship: ______________________________ Date: ______________________________

Test Zone: ______________________________ Team: ______________________________

Cable Tested: ______________________________ Transmit Antenna: ____________________

Transmit Frequencies (MHz)	Receiver Reading (dB/µV)	Probe Factor (dB/ Ω)	Current on Line (dB/ µa)	Time	Remarks
18.0					
19.0					
20.0					
22.0					
24.0					
26.0					
28.0					
30.0					

Table 7-2 Conducted Measurement Data Sheet (continued)

RADIATED RECEIVE LEVELS

Ship: ______________________ Date: ______________________

Test Zone: ______________________ Team: ______________________

Transmit Antenna: ______________________

Transmit Frequencies (MHz)	Receiver Reading (dB/µV)	Antenna Factor (dB/m)	Field Level (dB/µV/m)	Time	Position For Peak Reading Describe
2.0					
2.5					
3.0					
3.5					
4.0					
4.5					
5.0					
5.5					
6.0					
6.5					
7.0					
7.5					
8.0					
8.5					
9.0					
9.5					
10.0					
11.0					
12.0					
13.0					
14.0					
15.0					
16.0					
17.0					

Table 7-3 Radiated Measurement data Sheet

RADIATED RECEIVE LEVELS

Ship: ______________________ Date: ______________________

Test Zone: ______________________ Team: ______________________

Transmit Antenna: ______________________________________

Transmit Frequencies (MHz)	Receiver Reading (dB/µV)	Antenna Factor (dB/m)	Field Level (dB/µV/m)	Time	Position For Peak Reading Describe
18.0					
19.0					
20.0					
22.0					
24.0					
26.0					
28.0					
30.0					

Table 7-3 Radiated Measurement Data Sheet (continued)

COUPLING PATH DATA

Ship: ______________________ Date: ______________________

Test Zone: ______________________ Team: ______________________

Transmit Antenna: ______________________

Transmit Frequencies (MHz)	Coupling Path Description
2.0	
2.5	
3.0	
3.5	
4.0	
4.5	
5.0	
5.5	
6.0	
6.5	
7.0	
7.5	
8.0	
8.5	
9.0	
9.5	
10.0	
11.0	
12.0	
13.0	
14.0	
15.0	
16.0	
17.0	
18.0	
19.0	
20.0	
22.0	
24.0	
26.0	
28.0	
30.0	

Table 7-4 Coupling Path Data Sheet

8. CONCLUSIONS AND RECOMMENDATIONS

The results of the Phase 1 modeling effort show a great deal of promise when compared to data measured on the FFG-7 class. The comparison of measured and predicted levels in Section 4 have not been modified with curve fitting techniques such as regression analysis. Although good correlation is achieved in the data comparisons presented, it is expected that when these analysis techniques are applied and the prediction program is modified to account for them, even better correlation will result. One other significant point is that the measured data presented was collected on FFG-7 class ships where the topside was not modified to conform to MIL-STD-1310D. Now, extensive topside modifications have been made which should impact the electromagnetic environment below decks. When a complete below deck measured data set exists on the modified FFG-7 class ships, the prediction model will be modified to account for the level reduction. Once these model factors have been identified, the program should be capable of predicting net below deck electromagnetic environmental improvements resulting from topside modifications.

With the additional data to be collected in the Phase 2 effort the models can be refined and developed into a useful design tool. NAVSEA design engineers and others will be able to use the program to determine the radiated and conducted levels in various areas below decks. A better understanding of the coupling mechanism will result from the measurements showing how signals transfer from above deck structures to the below deck areas and also from structure to structure below deck.

The measured results will have a significant impact on evaluating the effectiveness of the MIL-STD-461B limits, the bonding, grounding and shielding practices recommended by MIL-STD-1310D, and the General Specifications for all new construction of ships.

If the prediction results are effective on the two classes of ships studied in Phase 2, then consideration should be given to extending this study to other classes such as the PHM, SNEP, CGs and CVs. Instead of the extensive measurement effort an attempt could be made to apply the formulas developed

in the Phase 2 effort to these ship classes and then validation measurements could be made. If reasonable accuracy is obtained, similar to the accuracy of the FFG-7 and DD-963 class, extensive measurement work would be unnecessary. Measurements would be reserved for those cases where very unique conditions exist.

Once the below deck prediction technique is established in the HF frequency range and an understanding of the coupling mechanism is accomplished, a plan should be generated to extend the capability to higher frequencies. The frequency band from 30 to 1000 MHz could be the next range. There are fleet reported cases of radars above 200 MHz that cause problems to below deck systems.

The work accomplished in Phase 1 shows the feasibility of developing a prediction capability for the electromagnetic environment below decks on ships in the HF frequency range. Phase 2 work will allow this capability to be fully realized. The result will be a useful design tool that can be utilized by both ship and equipment designers. It will also help to evaluate the usefulness of the specifications that are now in effect for equipment and ship design. The successful completion of the Phase 2 work will also lead to extending the technique to additional ship classes and greater frequency ranges.

APPENDIX

The appendix contains the three interim reports submitted during the Phase 1 work. The interim reports were submitted at forty-five day intervals reporting the progress and status of the work. They were submitted to NAVSEA, Code 61R4.

COMSEARCH
INCORPORATED

March 15, 1982

To : Commander
Naval Sea Systems Command
Naval Sea System Command Headquarters
Washington, D.C. 20365

Attention : Mr. H. DeMattia, NAVSEA 61R4

Subject : First Interim Report for DESAT Project, "Below Decks Electromagnetic Survey Study". Contract #N00014-82-C-0117

7633 Leesburg Pike/Falls Church, Virginia 22043-2599/(703) 356-9470

1. Introduction

This interim report reviews the activities and progress of the subject contract since award on 20 January 1982. The activity during this period has included meetings with the NAVSEA Scientific Officer and representatives of other organizations both U.S. Navy and private to coordinate the technical thrust of this effort so that the optimum benefit for the U.S. Navy could be achieved. Of the four work areas to be accomplished under this contract, development of measurement techniques, development of model synthesis techniques, the production of and overall task plan for the Phase 2 effort, and a test plan for shipboard measurements, work has been initiated in the first two areas. A description of the work accomplished in these areas, the work planned under the contract and supporting efforts during this initial period of the contract are described in this report.

2. Technical Support Activities

The main efforts in this category have been in attending technical meetings with the contract's scientific officer and other technical experts on the shipboard below decks EMI problem. This included personnel from the Naval Underwater Systems Center, the University of Pennsylvania, NAVSEA's SEMCIP program and the Eldyne Corporation. From these meetings a great deal of reference material was cited as being relevant to this task. This material has been obtained and suggestions were made to limit the thrust of the contract effort to make it more manageable and helpful to programs already in existance. Specifically, suggestions were that the technical effort concentrate on frequencies between 1 and 30 MHz, that the data be tailored to fit the existing low frequency prediction program format, and that identification of coupling paths to below deck areas be included in the data collection. Some discussion advanced the issue that the shipboard measured data would be more useful if the empirical approach of measuring a great number of samples was given a lower emphasis than measurements that described the coupling path to the below deck areas. This issue is presently being considered very carefully because it impacts the four areas of effort under the Phase 1 work.

It has been reported that HF interference has resulted in degrading interference to below deck systems on at least three new classes of U.S. Navy ships. They are the FFG-7, PHM and SNEP. There are also reports of HF interference causing interference to the AN/SPS-40 radar cabinets via below deck coupling on the DD-963 class. These problems all require the data collection and synthesis model development that this contract has undertaken.

Another support effort under this contract has been to look at the requirements of MIL-STD-461B with regard to below deck system. A memorandem describing the test requirements for SENSORS which would be applicable to transducers has been prepared for NAVELEX Code 832. Transducers have been the EMI susceptible element below decks on the FFG-7 class ships.

3. Planned Activity

Work in the development of measurement techniques and the development of model synthesis routines has been initiated. In the measurement technique area

a number of computer controlled systems have been investigated for suitability of shipboard use. Techniques of not only controlling the test equipment but also of computer data collection have been looked into. This effort is continuing. In the model synthesis area review of other programs has been undertaken. However, in this area since the empirical technique may be de-emphasized in favor of data collection with a detailed coupling path description, a different modeling effort may be undertaken. This is presently under consideration and an approach will be decided on shortly.

4. Activity for Next Interim Period (15 March - 30 April 82)

For the next interim period the effort will concentrate on the measurement technique area and decisions on where the data emphasis shall be. Once these decisions are made then the work in formulating the Phase 2 task plan and the shipboard test plans can be initiated. In order to facilitate both the measurement and modeling efforts decision, members of the Comsearch technical staff are going to visit the Naval Underwater Systems Center to observe their instrumentation and discuss their measurement efforts. This visit will be scheduled in the early part of April 1982.

5. Revised Schedule

On 3 March 1982, Comsearch requested the following changes to the contractual schedule:

Item No.	Report	Revised Date On or About	Original Date On or About
0001AA	Interim	15 March 82	15 February 82
0001AB	Interim	30 April 82	31 March 82
0001AC	Interim	15 June 82	15 May 82
0001AD	Final	31 July 82	30 June 82

The reason for the requested changes was the late notification of contract award. The schedule changes involve no additional cost.

COMSEARCH INCORPORATED

May 7, 1982

To : Commander
Naval Sea Systems Command
Naval Sea Systems Command Headquarters
Washington, D.C. 20365

Attention : Mr. H. DeMattia, NAVSEA 61R4

Subject : Second Interim Report for DESAT Project, "Below Decks Electromagnetic Survey Study". Contract #N00014-82-C-0117

1. INTRODUCTION

This interim report reviews the activities and progress of the subject contract during the period of 15 March to 30 April 1982. The activity during this period has included developing test methods and data formats that would make the output of this effort consistent with the work that has already been accomplished by the Naval Underwater Systems Center (NUSC). In addition to the test methods and model synthesis efforts work has now been undertaken in developing an overall task plan for the Phase 2 effort and a test plan for specific ship class measurements. A description of the work accomplished in these areas, the work planned under the contract and supporting efforts during the second period of the contract are described in this report.

2. TECHNICAL SUPPORT ACTIVITIES

2.1 Computer Analysis

The computer software already set up by NUSC as documented in the technical material they have supplied have been reviewed. Note has been made of several techniques which should prove to insure the success of the project. On the software side of the picture, these include an executive and module structure with independent module testing. A preliminary cull is helpful in eliminating cases which could bog down even the highest-speed computers.

Comsearch's plan to gather data will allow entry of the measured data into the NUSC data base. Any software developed will be compatible with the structure of the existing NUSC software and DEC hardware. Our addition to the existing methods is that exterior HF sources will be considered as causes of fields present below-decks. Our plan is to break the ship into several key zones, make extensive measurements in those zones, identify the special entry points of RF energy, and model the data in order to predict fields in zones where no measurements have been made. When programmed, this method will allow quick recalculation of the effects of cabinet movement, as desired.

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2.2 Measurement Techniques

Plans have been made to use automated measurement techniques in as many zones as possible. Field sensing devices, both conducted and radiated are being investigated along with their calibration factors. The calibration factors will be stored in the computer program so that the data reduction from the shipboard measurements will be greatly expedited.

Devices are being investigated to trace and determine the coupling path from the topside areas to the below decks areas and then throughout the below decks areas. Magnetic coupling devices seem to be the most suitable devices for this type of signal tracing.

3. PLANNED ACTIVITY

Work is now in progress in all four major categories of this task, measurement technique, development of model synthesis, Phase 2 task plan development and specific shipboard test plan. The modeling approach for the coupling path description is continuing.

4. ACTIVITY FOR NEXT INTERIM PERIOD (30 April - 15 June 82)

For the next interim period the effort will concentrate on the completion of the measurement technique and instrumentation selection. Modeling work will continue. A meeting with the technical staff of NUSC is scheduled for 19 and 20 May 82 to discuss existing data base and modeling programs and instrumentation used by the center for collecting data. Work will also continue in the Phase 2 task plan and test plan areas.

June 21, 1982

To : Commander
Naval Sea Systems Command
Naval Sea Systems Command Headquarters
Washington, D.C. 20365

Attention: Mr. H. DeMattia, NAVSEA 61R4

Subject : Third Interim Report for DESAT Project, "Below Decks Electromagnetic Survey Study". Contract #N00014-82-C-0117

1. Introduction

This interim report reviews the activities and progress of the subject contract work during the period of 1 May 1982 to 15 June 1982. The activity during this period has included developing a specific test plan for the FFG-7 and DD-963 class ships along with data sheets to be used by the field teams. Work has also been accomplished in the modeling area and a list of the assumptions, input requirements, methods and outputs has been prepared. A highlight of the work during this period was a trip to the Naval Underwater Systems Center (NUSC) on 19 and 20 May 1982 by Dave Hyduke and Les Polisky of Comsearch. Meetings were held with Mr. Dave Dixon and his staff to discuss how to best integrate the technical outputs of this contract into the existing NUSC programs. In addition, instrumentation used aboard ship by NUSC personnel to collect data was also examined.

2. Technical Support Activities

2.1 Computer Analysis

It has been decided to use portions of the Intra System Electromagnetic Modeling and Analysis Program (IEMCAP) as the foundation for the model programs in this effort. The modeling effort for this contract crossed the boundary of two existing U.S. Navy programs that now exist. Each deals solely either with the above deck or below deck areas. The program that will be developed in this effort will combine the two areas.

The modeling effort has been broken down into the following categories and subroutines to produce predicted levels.

1. Assumptions

    1) Exposure of cable length topside is defined or set to nominal length for ship class.
    2) The level along the cable below deck is considered constant.
    3) Topside energy transfer is not a function of angle.
    4) Indirect cable-to-cable coupling will be considered.
    5) Peak of standing wave will be predicted.
    6) Reflections above deck will not be considered.
    7) Cables above deck are assumed to be unshielded and run from deck to mast top perpendicular to the deck.
    8) Transmitting antennas will be considered point sources.

2. Input Required

1) Matrix of HF antennas versus topside cables listing minimum separation distance.
2) List of cables in each compartment.
3) Matrix of intercable separation in each room.
4) Frequency spectrum modifier (i.e. HF couplers and filters, cable attenuation characteristic versus frequency.

3. Models Required

1) HF to various cables and wires.
2) Cable-to-cable and wire-to-wire (includes conducted and radiated).

4. Methods

1) Read input matrices list of emitters.
2) Calculate entire transfer function situation to account for all factors.
3) HF to topside cable or wire which will yield spectrums below deck and predict peak radiated and conducted levels only.

5. Outputs

1) Predict peak radiated levels across frequency band in center of compartment.
2) Predict peak conducted levels on identified selected cable.
3) Comparison of predicted levels to measurements.

2.2 Measurement Techniques

Completely automated techniques may have to be confined to data storage and analysis. Data collection instrumentation will have to be non-automated because of the requirement of determining peak levels and the tracing of coupling paths. Cable and wire identification will also require a step by step approach. The test plan for the FFG-7 and DD-963 class of ships which is now being prepared reflects this approach.

3. Planned Activity

Work is continuing in all four major categories of this task. Special emphasis is now being made in the Phase 2 task plan development.

4. Activity for Next Interim Period (15 June - 31 July 1982)

In this next interim period which will be the final one the Phase 1 work will be completed and the final technical report prepared. The technical report will contain a description of the measurement techniques, development of model synthesis, Phase 2 task plan development and a specific shipboard test plan.

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